The Suitability of the SPAR-H "Ergonomics/HMI" PSF in a Computerized Control Room in the Petroleum Industry

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Abstract: This paper suggests changes in the "Ergonomics/HMI" PSF based on a review of current research on the HEP influence of ergonomic and HMI issues, an evaluation of the suitability of the SPAR-H "Ergonomics/HMI" PSF guidelines for the petroleum industry context, and interviews with HRA analysts. We recommend that the SPAR-H PSF "Ergonomics/HMI" should not be included in the Petro-HRA method as it is today. We suggest that the PSF description should be changed to suit the computerized control rooms in the petroleum industry. We suggest that that the PSF should include a level that corresponds to situations where the HMI is so bad that it is not reasonable to expect the operator to be successful at the task. We also suggest that at least one more PSF level is added to add nuance.

Keywords: HRA, HMI, Ergonomics, Petro-HRA, SPAR-H

1. INTRODUCTION

In the Petro-HRA project [1], we attempt to adapt the nuclear intended Standardized Plant Analysis Risk – Human Reliability Analysis (SPAR-H) method to the petroleum industry. All aspects of the method are evaluated, including all of the eight performance shaping factors (PSFs) included in SPAR-H. The SPAR-H method is a human reliability analysis (HRA) method that estimates human error probability (HEP) through multiplying a nominal error rate with PSFs [2]. This paper suggests changes in the "Ergonomics/HMI" PSF based on a review of current research on the HEP influence of ergonomic and HMI issues, an evaluation of the suitability of the SPAR-H "Ergonomics/HMI" PSF guidelines [2, 3] for the petroleum industry context, and interviews with HRA analysts. Six of the other PSFs from SPAR-H are discussed in another paper submitted to PSAM12; "Available time", "Stress/Stressors", "Experience/Training", "Procedures", "Fitness for Duty", and "Work Processes" [4]. The "Complexity" PSF from SPAR-H is evaluated in previous paper [5].

In this paper we define ergonomics as both the environment in which the operators work (i.e. noise, heat, lighting, radiation) [6] and the way the operators interact with the system (e.g. working position, work station layout, work surface, and human-machine interface (HMI)) [7, 8, 9]. HMI is defined as the system-interface the operator is working with. The system-interface can be both an analog hard-wired system with knobs and levers and a computer interface.

Several large accidents, such as Three Mile Island, Bhopal and Chernobyl, were originally considered to be caused by simply "operator error", "human failure" or the "human element". Further investigations into these accidents found that many factors, including several ergonomic, played an important part in the scenario that led to the accidents [10]. A failure to understand the HMI was found to be one of the causes of the Chernobyl accident [10] while operators at the Bhopal plant failed to identify the situation due to a gauge being placed on site and not in the control room, and due to a control panel having been removed from the control room (possibly for maintenance) [10]. The Three Mile Island accident has undergone the most thorough investigation creating a long list of ergonomic issues, several that had a direct effect on the accident scenario; poor instrument placement, inconsistent instrument functioning, contradictory and contra intuitive use of colors, lights, levels and knobs (see [11, 12, 13] for an exhaustive list). The influence of ergonomics in large accidents has led to many of the existing HRA methods to include it in the estimation of the human contribution to risk (e.g. HEART [14], THERP [15], JHEDI [16], and SPAR-H [2, 3]). However, as technology advances

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and changes the way work is being done, the ergonomic factors change with it (e.g. proper monitor lighting only become an issue as monitors where introduced while proper design of physical lever is no longer an issue in control rooms that no longer use physical levers). To ensure that the current challenges are addressed, HRA-methods need to stay updated. In SPAR-H, HMI and software have been included in the "Ergonomics/HMI" PSF. However, there are large differences between control rooms in the petroleum industry today [17] and the control rooms at nuclear power plants (NPPs) [18], and even larger differences between today's petroleum industry control rooms and the NPP control rooms from the time THERP, the method that SPAR-H is partly based on, was developed. NPPs still rely to large extent on conventional control devices such as physical knobs, dials and levers that are fixed in one place [18]. In the petroleum industry the operators interacts with a computerized system in practically all of the operator's safety critical tasks [17]. This leads to differences in the ergonomics issues that can influence the HEP and whether ergonomic and HMI challenges in today's petroleum industry are covered by existing HRA-methods needs to be addressed.

2. INTERVIEWS

To investigate how HRA methods, and specifically SPAR-H, were being applied today HRA-analysts were interviewed in a semi-structured interview with questions on their experiences, approach choices (e.g. data collection, decomposition, if and how to choose a scenario), challenges they've faced and their suggestions for improvements. So far five HRA-analysts have been interviewed. Additional interviews will be conducted before any final decisions in the Petro-HRA guidelines are made.

Three themes related to the "Ergonomics/HMI" PSF from SPAR-H were recurring in the interviews.

1. Difficulties in reducing everything related to ergonomics and HMI into the choice of just one PSF level (the PSF levels in "Ergonomics/HMI" are; "good", "nominal", "poor" and, "missing/misleading" [2]). One analyst had experienced to be in a situation where he evaluated the general HMI in the control room to be good, while one aspect of the information presented to the operator that was relevant in the specific scenario he was investigating could have been clearer. The analyst found it challenging to choose between setting the "Ergonomics/HMI" to "good", based on the general evaluation or to "poor" based on the small aspect of the HMI that could have conveyed the information clearer.

2. The second issue was a lack of reference points. When evaluating if the ergonomics and the HMI are good, nominal or bad a point of reference or comparing is required. While SPAR-H does offer guidance on this, the analysts wanted clearer descriptions.

3. The third issue was low inter-rater reliability due to differences in PSF choice. Several of the HRA-analysts had experienced that they often disagree with other HRA-analysts on which PSFs that should be attributed in a situation. This is an issue that is related to several PSFs, and an issue that could have a great impact on the HEP as different PSFs have different multipliers.

3. LITERATURE REVIEW

3.1 Current research

In a recent review article Hickling & Bowie [19] reviewed the contribution of HMI with computers to the HEP in experienced personnel and compared the results to appropriate HRA methods (the findings are further discussed in Hickling [20]). The review separated tasks into two types; object level error data and holistic error data. Object level data is data on a very low level involving a specific task and involving a particular aspect of the HMI (i.e. interaction with a menu or icon). Holistic errors are at a higher level and involved a scenario where the task performer failed or succeeded when interacting with the HMI (i.e. "Single person task with no opportunity for error recovery") [19].

The object level data included 15 HMI interactions from 14 studies [19]. These were compared to THERP as it was considered the most appropriate HRA method for comparisons at an object level. Even while choosing the best HEPs from the studies, the results showed that THERP underestimated the HEP with a ratio of 10-100 [19]. The holistic data reviewed included holistic tasks from five studies. Also here the results were compared to THERP. For typical tasks the HEP found in recent studies was 10 times higher than the values in THERP [19]. Holistic tasks involving automation knowledge and expert systems also showed THERP to be too optimistic (no ratio was provided).

Hickling & Bowie's review also included a comparison between the HEP found in research on diagnostic tasks and the HEP from HRA methods. Few studies were found with this approach and this section of the review is heavily dominated by Bye et al. [21] and Broberg et al. [22] reporting from the same set of data. In addition, the scenarios in these studies also included unreliability from plant fault characteristics making the HEP contribution from HMI hard to determine. Nevertheless, Hickling & Bowie conclude that "processing of the available data suggest that the SPAR-H approach is not justified" [p. 24 in 19], and conclude the review with that SPAR-H likely produces optimistic HEP in all types of HMI tasks.

3.2. THERP

The multipliers connected to the levels in the "Ergonomics/HMI" PSF in SPAR-H are based on and calibrated against the HEP values from THERP [2, 23]. Therefore, an evaluation of "A Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications" [15] where THERP is presented was performed. THERP does not use the term HMI, but rather the term "man-machine interface" (MMI). The description given of MMI is close to what SPAR-H describes as HMI, but THERP's MMI does include some aspects that would be outside of HMI, such as; "Man-man interfaces refer specifically to person-to-person communication or other interaction; in the Handbook, the term man-machine interfaces includes man-man interfaces" [p. 2-2 in 15], and; "Since written materials direct the performance of people in a man-machine system, they are part of the man-machine interfaces in a system" [p. 2-14 in 15] These aspects are likely to be included in the "Work Processes" and the "Procedures" PSFs in SPAR-H. Differences in included areas and definitions can be problematic when HEP values or multipliers are based on or calibrated between methods.

The handbook also clearly states that the values used are based on the current state of NPPs; "In future plant designs, if sound ergonomic practices are followed (cf [24]), large improvements in operator reliability can be expected because many of the factors contributing to operator error will be eliminated, including unnecessary alarms. The model and HEPs in this section reflect the design of present plants [p. 11-39 in 15]". How to define "sound ergonomic practices" and to decide whether they are being followed today are discussions by themselves, but as the ergonomic situation and ergonomic challenges are substantially different in the petroleum industry today than it was in the nuclear industry when THERP was published it's likely that the petroleum industry is outside of the area that Swain & Guttmann [15] intended the HEPs in THERP to be applied in.

3.3. SPAR-H Guideline Evaluation

<u>3.1.1 Description of the "Ergonomics/HMI" PSF in SPAR-H.</u>
In this section the SPAR-H guidelines [2] and the complementary SPAR-H Step-by-Step Guidance [3] are evaluated in terms of transferability to the petroleum industry with current research and industry differences in mind.

The description of "Ergonomics/HMI" in the SPAR-H manual [2] is:

> Ergonomics refers to the equipment, displays and controls, layout, quality and quantity of information available from instrumentation, and the interaction of the operator/crew with the equipment to carry out tasks. Aspects of human machine interaction (HMI) are included in this category. The adequacy or inadequacy of computer software is also included in this PSF. Examples of poor ergonomics may be found in panel design layout, annunciator designs, and labeling. [p. 24 in 2]

This section shows that SPAR-H does cover HMI and software, but also that it is only a small part of the PSF. With the importance computerized systems have in control room settings in the petroleum industry and the underestimation of the HEP influence displayed in the literature in mind, increasing the HMI and software focus could give a more valid result in terms of which aspects that contribute to the HEP today. The description of “Ergonomics/HMI” in the SPAR-H manual continues with:

> When considering panel design layout, event investigations at U.S. commercial nuclear facilities have shown that when necessary plant indications are not located in one designated place, it is difficult for an operator to monitor all necessary indications to properly control the plant. If there is evidence that this is the case, a negative PSF value is assigned. [p. 25 in 2]

Layout issues still exist in today’s petroleum control rooms, but they are different than the ones seen in a traditional hard-wired system. Today large physical distances between indicators are rare but as the operators have a massive amount of information available, the HMI quality will greatly influence how much of the relevant information that reaches the operator. This could be a significant HEP contributor in cases where task relevant information is poorly conveyed through the monitor interface or the HMI is based on inter-page navigation that could hide relevant information. There is a lack of research on how these specific issues contribute to HEP or performance [19]. The description of “Ergonomics/HMI” in the SPAR-H manual continues with:

> Examples of poor annunciator designs have been found where only a single acknowledge circuit for all alarms is available, which increases the probability that an alarm may not be recognized before it is cleared. Another problem exists where annunciators have set points for alarms that are set too near to the affected parameter for an operator or crew to react and perform a mitigating action. Examples of poor labeling include instances where labels are temporary, informal, or illegible. In addition, multiple names may be given to the same piece of equipment. Ergonomics of the plant are also called the human-machine interface (HMI) or the human engineering aspects. Job performance aids can also be considered a special case of ergonomics. However, in SPAR-H, if the job performance deficiency is related to a procedure, then the preferred means of evaluating the situation is to apply this information to the procedures PSF, as opposed to the ergonomics PSF. For example, if the procedure does not match the equipment to be used, then the equipment procedure deficiency should be noted in the procedures, not the ergonomics, PSF. [p. 25 in 2]

The issues of informal or temporary labeling will perhaps be less frequent in a computerized control room, while illegible labels (or other parts of the displayed information being illegible) and non-consistent naming of equipment are still possible problems. This section also provides some clearance to where to attribute problems that are connected to more than one PSF. A good guidance on this will increase inter-rater reliability and avoid double counting.

3.1.2 Evaluation of the SPAR-H PSF levels

SPAR-H includes four PSF levels (five if you count “insufficient information”, which has the same multiplier as the “nominal” level) for the Ergonomics/HMI PSF:

> Missing/Misleading—the required instrumentation fails to support diagnosis or post diagnosis behavior, or the instrumentation is inaccurate (i.e., misleading). Required information is not

> available from any source (e.g., instrumentation is so unreliable that operators ignore the instrument, even if it is registering correctly at the time). [p. 25, 2]

Additional information provided in the SPAR-H Step-by-Step Guidance: "Note that this PSF level also includes failed and faulty instrumentation and indications" [p. 11 in 3]. The "Missing/Misleading" PSF is given a multiplier of 50 in SPAR-H [2]. THERP does not include a separate level for "Missing" scenarios, but it includes levels that correspond to "Misleading". The multiplier is adapted from highest normal operation condition interface related HEP in THERP, 0.05, which corresponds to "interfaces in which the design "…violates a strong population stereotype and operating conditions are normal" [Table 20-12 in 15] for an error of commission in operating manual controls" [p. 5 in 23]. There is a higher HEP level in THERP as well, but it assumes a situation with high stress. Stress is covered by another PSF in SPAR-H, so this HEP level was not included. It is realistic to imagine a situation where the ergonomics or the HMI influence the performance of the operator in such a way that it is unreasonable to expect that he or she will ever succeed. Therefore we would argue that the highest PSF level in this PSF should give a HEP of 1. The situation described in the PSF level description in SPAR-H described such a scenario, where the instrumentation does not support diagnosis and the information is not available from another source. However this would have to be clearly described in the PSF level description to avoid those situations that are considered to be slightly misleading or situations where correct information is collected from another source to get an HEP of 1.

> Poor—the design of the plant negatively impacts task performance (e.g., poor labeling, needed instrumentation cannot be seen from a workstation where control inputs are made, or poor computer interfaces). [p. 25 in 2]

This PSF level has adopted the value from "unclearly or ambiguously labeled" in THERP with an HEP of 0.01 [23]. The "Poor" PSF level in SPAR-H is given a multiplier of 10 [2]. Only having one PSF level between the "Misleading/Missing" level with a 50 multiplier and the "Nominal" level with a multiplier of one does not give the analyst the nuance he/she might desire. However, increasing the number of PSF levels will potentially create other problems such as lower inter-reliability. How to define the poor level, or poor levels, will be one of the most important aspects of this PSF. If the analyst is presented with subtle differences between several poor levels and the "Missing/Misleading" level it is unrealistic to expect high inter-rater reliability. Workshops with operators and analysts can be used in combination with the published research to write a precise definition and set a correct multiplier for these levels.

> Nominal—the design of the plant supports correct performance, but does not enhance performance or make tasks easier to carry out than typically expected (e.g., operators are provided useful labels; the computer interface is adequate and learnable, although not easy to use). [p. 25 in 2]

The SPAR-H Step-by-Step Guidance adds; "Again, as with all PSFs, the nominal level should be assigned whenever the analyst judges the PSF as not a performance driver." [p. 11 in 3]. The "Nominal" PSF level multiplier is set to 1 [2] and corresponds to the "clearly and unambiguously labeled" HEP of 0.001 in THERP [23]. This level needs to be available in all PSFs for instances where the PSF is considered not to be a relevant PSF, or for other reasons was set to nominal.

> Good—the design of the plant positively impacts task performance, providing needed information and the ability to carry out tasks in such a way that lessens the opportunities for error (e.g., easy to see, use, and understand computer interfaces; instrumentation is readable from workstation location, with measurements provided in the appropriate units of measure). [p. 25 in 2]

The "Good" PSF level multiplier in SPAR-H is 0.5. SPAR-H used expert judgments to set this multiplier and "do not have a direct link back to THERP or to empirical data" [p. 4 in 23]. The multiplier was set at a conservative level to avoid over-crediting [23]. Although not specifically referenced by SPAR-H, THERP similarly decreases the HEP by a factor of between two to ten from application of good ergonomics practices to nuclear power plants [Table 3-8 in 15]. If the nominal error rate is based on the average or the industry standard, there is a need to include a PSF level that gives the analyst the possibility to reduce the HEP for cases where installations are better than the average or the industry standard.

> "Insufficient information - if you do not have sufficient information to choose among the other alternatives, assign this PSF level". [p. 25 in 2]

This level needs to be available, either through the nominal level or through a separate level, in all PSFs for instances where information could not be collected. Keeping it as a separate PSF will not influence the HEP, but it will provide additional qualitative information in the analysis, as it highlights that this PSF is not included in the HEP, thereby giving an HEP that assumes that the PSF does not increase or decrease the HEP.

3.4. HEP Influence of Other Ergonomic Factors

Several reviews and meta-studies based on hundreds of studies exist on the effect working conditions have on performance. Two of the areas that have received the most attention are noise and temperature. Noise is generally found to have a significant but weak effect on performance [25, 26]. The effect is determined by duration and intensity, however the noise only had a moderate effect on accuracy at 145 dB or more (a jet takeoff is approximately 140dB [27]) [25]). The duration is less straight forwards as some noises are habituated while others are increasingly distracting over time [25]. A weak to moderate effect is found for both heat and cold [25, 28, 29]. The effect of cold on performance is a primarily found to be caused by a deterioration of motor functions, as cognitive tasks are less affected [25].

Several other effects of exposure to unpleasant levels of noise and temperature at work have been found, such as decreased job satisfaction [7, 30] and increased absenteeism [31, 32], making them areas that should be evaluated. However, the effect on HEP seems to be lower than the lowest PSF multipliers included in SPAR-H today (2, which indicates a 100% increase in HEP).

4. RECOMMENDATIONS

This paper represents a work in progress and the recommendations made here are only recommendations. More work, including additional interviews and workshops with HRA-analyst, petroleum control room operators and experts will be done before the final PSF structure, PSF definitions, PSF levels and PSF multipliers are ready.

3.1 The PSF Description

We would recommend that this PSF should only focus the interaction between the operator and the computerized system and leave out other ergonomic factors related to the physical working environment such as noise and temperature. This recommendation is based on (1) the relatively weak impact these factors have shown to have in meta-studies, (2) to ensure that new challenges due to working in computerized control room is covered, and (3) to reduce analyst difficulties in attributing a large area in one PSF. We also recommend that the PSF should be called "HMI". The description of the PSF needs to be adapted to the computerized control rooms found in the petroleum industry. Guidance on what should be evaluated and reference points on HMI quality could be taken from the standards used in the petroleum industry (e.g. [17]), existing HMI evaluation tools on usability (e.g. [33]), and current research.

The third recurring theme in the interviews involved choosing a PSF level when good arguments could be made for more than one level, exemplified by a generally good HMI that included one aspect which would be described as poor. We recommend that the Petro-HRA guidelines specifically state that what should be evaluated is how the HMI affect the operators' performance in the specific task that is being analyzed. The general quality of the HMI or potential problems with the HMI that is outside of this task should be added as an additional qualitative comment.

3.3 PSF Levels and Multipliers

We consider it realistic that situations could occur where the HMI degrades performance to such a degree that it is unreasonable to expect that the operator will ever succeed. Therefore we recommend that the highest PSF level ("Missing/Misleading") in this PSF should give a HEP of 1. It is important that this level is clearly described as a level that should be chosen only in situations where HMI alone is influencing the performance to such a degree.

If the impact of the "Missing/Misleading" PSF level is increased to always result in HEP equals one then the PSF will only include one PSF level ("Poor") that degrades performance without always ending in an error. The "Poor" PSF in the "Ergonomics/HMI" PSF in SPAR-H has a multiplier of 10, which would lead to a HEP of 0.1 for diagnostic tasks and 0.01 for action tasks (if no other PSFs are degrading or enhancing performance) [2]. Hickling & Bowie's [19] review found several studies where the "Poor" PSF level would probably have been chosen and underestimated the HEP, but also several where the "Poor" PSF level would have been chosen and the HEP would have been overestimated. A functional HRA-method will never have the flexibility to predict the exact results all HEP studies, but through adding one or two more levels of that degrade performance the analyst will be able to give a more nuanced description and calculation of the HEP influence from this PSF.

Choosing valid multipliers for the PSF levels will an important and challenging task in the development of the Petro-HRA method. Workshops with HRA-analyst, petroleum control room operators and experts that have knowledge of current research will be conducted and preferably be combined with objective data from simulators and databases. Whether the multipliers are chosen through a workshop, or in a combination with objective data, it is important that how and why the multiplier was set is described clearly in the guidelines. Without this documentation it is unreasonable to expect anyone to have faith in the results produced with this method.

3.4 Other Ergonomic Factors

An evaluation of whether the other ergonomic factors outside of HMI are influencing HEP to a large enough extent that they should be included in a PSF or be a separate PSF in the final guidelines must be done. We recommend that they are not included in this PSF, and based on the review and meta-studies evaluated in this paper we recommend that these factors (noise and temperature) are not included in the Petro-HRA method.

In today's SPAR-H these factors are covered by the "Stress/Stressors" PSF. In another PSAM 12 paper [4] we recommend that it should not be included there either.

5. CONCLUSION

We recommend that the SPAR-H PSF "Ergonomics/HMI" should not be included in the Petro-HRA method as it is today. We suggest that the PSF description should be changed to suit the computerized control rooms in the petroleum industry. We suggest that that the PSF should include a level that corresponds to situations where the HMI is so bad that it is not reasonable to expect the operator to be successful at the task. We also suggest that at least one more PSF level is added to add nuance. Workshops with HRA-analysts, petroleum control room operators and experts with knowledge of current research should be used to define the PSF and set the multipliers, preferably in combination with objective data from simulators or databases of errors in the petroleum industry. While this work will largely revolve around the quantification part of the method, it is important to remember that the qualitative feedback given in HMI should be seen as a valuable input to recommendations of improvement given.

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